A Non-Contact Human Body Height and Weight Measurement Approach using Ultrasonic Sensor

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Abstract. Human body height and weight are the key factors for personal health monitoring and many works have been conducted to accurately and conveniently measure these two physiology parameters. However, in many conditions such as in the outer space, measuring human body weight becomes impossible for traditional approaches such as using weight scale. In this paper, we present a medical instrument, called the Ultrasonic Measurer to measure human body height and weight using a non-contact approach. This is a low-cost, efficient device to estimate human body sizes using an ultrasonic sensor, the SRF04. This sensor provides good measurements in close distance over a range up to 300cm. Moreover, we present a convenient approach to estimate human body weight from the measured sizes using the close relationship between a human body's weight and its sizes, despite the variation in shapes. The measurements and estimations were implemented on a set of 50 men and women with different body shapes. The proposed method proved to give good results as the sizes are estimated with the average error of less than 0.3% and weight is estimated with the average error of less than 2.8%. The module is currently designed to be used as a standalone device. In the future, the module is equipped with the Internet of Things (IoT) for various remote health monitoring applications.

Keywords: Non-contact human body measurements, ultrasonic sensor, medical instrumentation, health monitoring.

1 Introduction

Human body parameters convey a lot of valuable information about an individual's physical status, shape, size, physique, and body composition [1]. Non-contact human body measurement is playing an increasingly vital role in physical healthcare, surveillance [2] and the demand for determining these indexes is inevitable. Over the centuries, people use a weight scale and a measuring tape to measure the human weight and height. However, accuracy still stands as a problem of these traditional methods. Although the advance in technology such as digital measurement techniques can minimize the error, there still exist many practical circumstances that need a specific tool. For instance, when an astronaut is in space, which is nearly weightless, he/she cannot use a scale to measure his/her weight.

Systematic attempts to characterize and estimate the main anatomical and compartmental components of the human body weight have been proposed and reviewed for a long time [3]. Sendroy and Collison, in [4], determined the human body volume from height and weight and then constructed a diagram for the relationship of V/S (Volume/Surface area) to W_E/H (Weight/Height) for male and female body and the most acceptable relationship between V and S, W_E and H. This approach gives an estimation of human body volume from height and weight and proposes an idea of some relationship between the human body's dimensions and its weight, which is critical for the human body weight estimation without using a weight scale. In the last decades, researchers have begun to measure body parameters indirectly using modern devices and methods.

Recently, marker-less multi-view systems have become proficient at obtaining human body models but these solutions usually require large space and the measurements are difficult to set up [2]. Some other devices such as laser or Kinect camera [2] can present a convenient way to estimate human body volume; however, these methods are quite expensive since a three-dimensional laser scanner may cost from $40.000 to $150.000 US dollar [2]; the Microsoft's Kinect sensor V2 costs more than $300. In addition to high investment cost, the above system requires complicated algorithm running on a computer to provide the measurements. Choosing the ultrasound transducers can solve this problem because they are small, lightweight and cheap, making them suitable for placing the sensors on several human body segments [5], thus proposes a natural way to determine the volume of an object. This paper describes the development of a fairly accurate, cheap, and standalone human body height and weight measuring using a system of ultrasonic sensors SRF04 and the Arduino microcontroller. The algorithm to calculate weight based on the study of the relationship between a human body's volume and its weight is presented in the following sections.

The paper is organized into five sections. After the introduction, section 2 depicts the method to implement an effective algorithm in a low-cost hardware. Section 3 shows the results and the corresponding error rate. Section 4 presents the advantages and drawbacks of the work and then propose further improvements. Finally, section 5 contains conclusion and scope for the future investigations.

2 Method and Material

2.1 Ultrasonic sensor SRF04

This ultrasonic sensor is a product of Devantech Limited company where SRF stands for ultraSonic Range Finder. The ultrasonic range sensor SRF04 has 2 heads, one for ultrasonic wave emission and the other for wave receiving. The unit pinouts are connected to the microcontroller unit, the Arduino Uno R3 in this case. These pins are responsible for triggering and measuring the time-of-flight of the echo [6]. The emission head emits ultrasonic wave whenever it is triggered by a triggering pulse. The frequency of the ping wave is 40 kHz [7]. The wave will reflect upon hitting an obstacle along its transmission path and the other head captures this reflection wave. The integrated timing circuit looks for a 40 kHz return signal to identify it as an echo [7]. The distance between the sensor and the obstacle is calculated based on the time-of-flight and the velocity of the ultrasonic wave. The sensor provides good measurements in close distance over a range of [3cm, 300cm] with approximately 99% accuracy [8].

Fig. 1. Ultrasonic range sensor SRF04 [8]

2.2 The Integrated Circuit

The main circuit was designed as shown in Figure 2. In addition to the SRF04 sensor, one resistor, one microcontroller Arduino Uno R3 and a LCD (liquid crystal display) screen are required. The sizes are first calculated by the ultrasonic sensor and then the information is sent to the Arduino microcontroller to calculate the weight based on the volume information and the density of a human body. Eventually, the weight and height are visually displayed on the LCD.

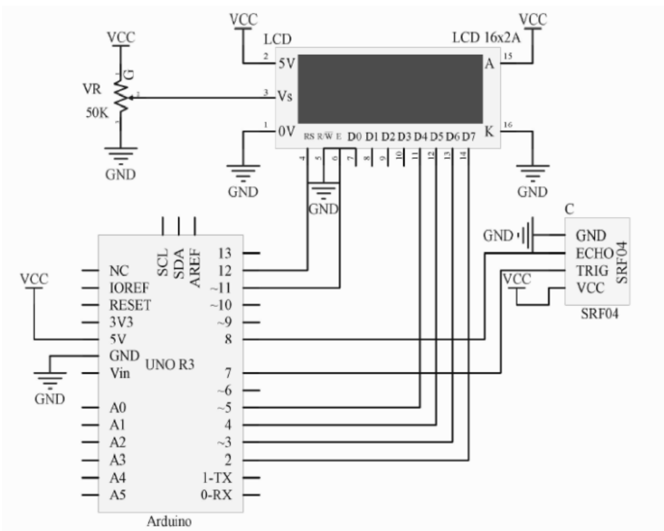

Fig. 2. Schematic of the designed circuit

2.3 Algorithm

Figure 3 shows the algorithm to estimate the human body's dimensions (i.e., height, frontage, and width). These values are then used to calculate the volume and subsequently, weight of a human body. The measured height and weight results are then displayed on the LCD screen.

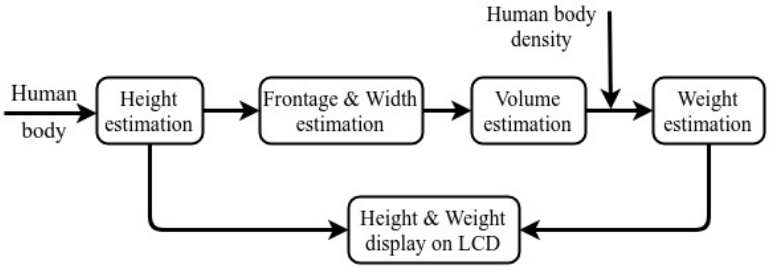

Fig. 3. Structure of the proposed algorithm for weight and height estimation

The dimension Height (*H*), Width (*W*), Frontage (*F*) of a human are defined as illustrated in Figure 4:

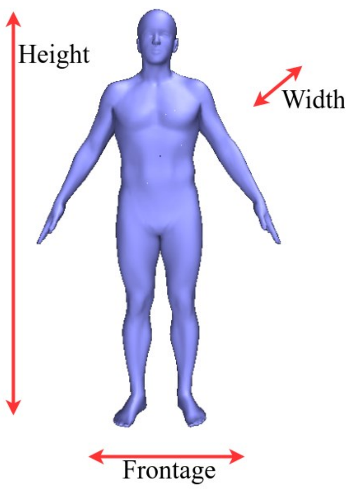

Fig. 4. Defined dimensions of a human body

Height, Frontage and Width measurement. All of the dimensions (height, frontage, width) are measured using one common principle. For example, *W* (width) of a human body equals the distance between the sensor and the reference point, *b*, subtracts the distance between the sensor and the body, *a*, provided that the human is standing just beside the reference point:

$$W = b - a \tag{1}$$

The principle is illustrated in Figure 5. In order to have an accurate result, the distance between the sensor and the reference point is made unaltered. In other words, b is a constant. Moreover, the body being measured needs to stand right in the transmission path of the ultrasonic wave. As illustrated in Figure 6, the width W is measured many times across the upper part of the body and the mean of these values is calculated to get the estimated W value. Taking the mean value would help reduce the error caused by the instability of the body parameters because when human takes breath, the parameter of the waist will increase while the parameters of other parts will hardly change. To further increase the accuracy of the measurement, the beam width should be narrowed by installing a paper tube around both heads of the sensor [8]

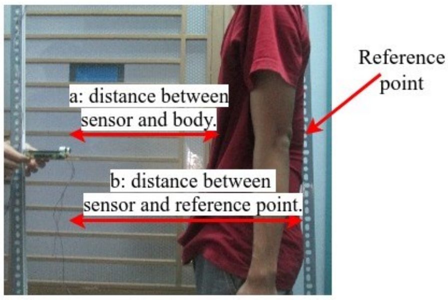

Fig. 5. Dimension Width (W) estimation using sensor

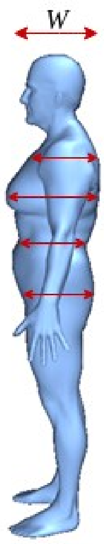

Fig. 6. Estimated W value is the mean of the measured values

Volume estimation. Volume V of a human body is estimated as a first-order function of 3 independent parameters:

$$V = H.F.W.\alpha \tag{2}$$

where α is the compact coefficient. We have determined the value of this coefficient by measuring the body parameters (height, weight, frontage) and the true value of the human body volume (measured by water displacement technique [3]) of a set of 50 men and women with the ages between 15 and 60 and infer the value of α from these measured values. The estimated α value of the sampled human bodies is 0.385 and this value is used to estimate the volume of Vietnamese human bodies since Asian population demonstrates significantly small variation in key body measures within population [9]. This value is critical for an accurate estimation of the human body volume. Experimental measurements show that although the value of α varies with the physical shape of the body of interest, from person to person as well as from men to women, the value lies in the range of [0.37; 0.41].

Weight estimation. After having an estimated value of human body volume, we can easily get a quite accurate estimation of human body weight (W_E) using the formula:

$$W_E = V.B \tag{3}$$

where Weight is calculated in kg, Volume is calculated in m^3 and B is human body density whose average value is approximately 985kg/m^3, according to [3].

3 Experimental Result

Figure 7 is a photograph of the implemented circuit board which contains 3 components: the Arduino microcontroller, the ultrasonic sensor SRF04 and the LCD screen. The measurements were conducted on 12 distinct individuals, (6 men, 6 women with the ages between 15 and 60). Each subject was measured 3 times. The α value being used is 0.385. The two tables below show the results of the experiments.

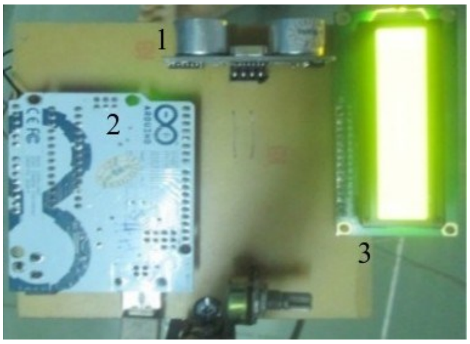

Fig. 7. The implemented board for the measurements with 1 - the ultrasonic sensor, 2 - the Arduino Uno R3 and 3 - the LCD screen

Table 1. Measured heights and weights.

Person	Measured heights (cm)			Measured weights (kg)		
	1st	2nd	3rd	1st	2nd	3rd
1	174	175	175	57.74	59.93	61.32
2	174	173	172	78.92	67.84	75.01
3	171	169	172	57.87	54.67	56.13
4	157	160	159	64.78	63.23	62.76
5	173	176	174	60.24	64.97	65.61
6	165	168	169	59.67	66.83	65.55
7	175	176	177	52.51	55.43	55.56
8	164	167	168	76.71	75.03	88.96
9	169	171	171	65.45	67.16	71.33
10	180	181	181	70.12	71.35	72.06
11	185	185	184	75.55	76.72	74.42
12	192	193	192	78.82	77.58	79.05
Average variance			*1.13*			*7.48*

One can see that while the variance of the measured height values is quite small and neglectable, the variance of the measured weight values is quite high compared to other electronic devices. This is due to the inaccuracy of the dimension estimations (i.e., frontage estimation and width estimation) when the individual who is under the test takes in a breath and thus changes his/her overall body volume. Height measurement is, in some senses, a simple measurement compared to the weight measurement.

Table 2. Errors in the measurements.

Person	Average height	Real height	Error (%)	Average weight	Real weight	Error (%)
1	174.67	175	0.1	59.66	57	4.67
2	173.00	174	0.5	73.92	75	1.44
3	170.67	170	0.3	56.22	55	2.22
4	158.67	159	0.2	63.59	61	4.25
5	174.33	175	0.3	63.61	62	2.59
6	167.33	168	0.3	64.02	63	1.61
7	176.00	177	0.5	54.50	52	4.50
8	166.33	166	0.2	80.23	83	3.30
9	170.33	170	0.2	67.98	70	2.90
10	180.67	181	0.18	71.18	70	1.69
11	184.67	185	0.18	75.56	77	1.88
12	192.33	192	0.17	78.48	80	1.90
Average error			*0.26*			*2.75*

Table 2 shows the errors in the height and weight measurements, which depend on the inaccuracy of the sensor, the value of α (compact coefficient) and the value of B (human body density). A comprehensive inspection of the value of α and B can help reduce the error to less than 2.3%.

4 Discussion

In this paper, we described the design and implementation of a device which can estimate the human body height and weight through a non-contact approach using the ultrasonic sensor. This method of measuring human body weight and height does not outperform traditional methods (with less than 0.1% lower accuracy in the height measurement and less than 1.5% lower accuracy in the weight measurement). However, this method overcomes one major drawback of traditional weight measurement method (using weight scale) is that the output measured weight changes with altitude due to the change of the gravitational acceleration value with altitude. When compared to other products to measure human body's height and weight such as the infrared laser of Microsoft's Kinect camera, our product cost is much lower. The system cost will reduce drastically if it is in mass production. One of the ways to reduce the cost of the product is to replace the Arduino microcontroller with specific ICs (Integrated circuit), which are equivalent to the Arduino microcontroller with a lower price. Although accuracy is not one of the advantages of the product, we strongly believe that we can improve its quality and accuracy in the future. The following subsections discuss the advantages, drawbacks and the ways to improve the accuracy of the system.

4.1 Advantages

Our product provides a simple approach for measuring human body height and weight that differs from other traditional methods when the body weight is estimated through its dimensions/sizes. It helps to:

- Overcomes one major drawback of traditional weight measurement using weight scale: the output measured weight changes with altitude due to the change of the gravitational acceleration value with altitude.
- Integrate height measurement and weight measurement in one measurement device.
- Measure human body parameters without any limitation to the height and weight value range of the body being measured.

It is easy to increase the range of the measurement by switching to a better ultrasonic sensor.

4.2 Drawbacks

There still exists some shortcomings in the projects, some major imperfections are:

- In order to have a reasonable result, the person needs to stand just beside the reference point.
- His/her clothes should fit tightly to his/her body so that the volume estimation step would give a reasonable result.

4.3 Improvements

In the future, to improve the product's performance, we suggest some solutions:

- Setting costume requirements for human body measurement. People should wear tight clothes to reduce error in estimations.
- Improving the accuracy of the sensor by replacing the SRF04 sensor with a better, more advanced sensing technologies such as laser, infrared or magnetic sensor.
- Improving the accuracy of the volume estimation by providing a more accurate value of α and human body density B using statistical analysis method.
- Programming the device to automatically taking measurements and sending the measured data to the user using IoT technology.

5 Conclusion

Using a system of ultrasonic sensor and Arduino development platform, we can measure the height, the width and the frontage of the human body, then calculate its volume and subsequently, its weight based on the human body's density information. While the measured height is very close to the real height with less than 0.3% error, in the weight measurement operation, there are still some substantial errors. It is understandable since the depth of a human body changes when the person breaths. Breathing leads to the change in the human body's volume and subsequently, to the error in the weight measurement. Moreover, clothing is one of the elements that make the results inaccurate. Therefore, we recommend that people should hold their breath and wear tight clothes during the measurements.

Conflict of Interest

The authors declare that they have no conflict of interest.

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